Environmental Radioactivity

Bogdan Pucelj

J. Stefan Institute
Ljubljana, Slovenia

TOPICS

- Natural radioactivity
- Human activities
  - Nuclear weapons tests
  - Chernobyl accident
  - Goiânia accident

Environmental Radioactivity - Sources

- Natural Radiation
  - natural radionuclides
  - cosmic radiation

- Man-made radionuclides
  - environmental contamination from
    * nuclear weapons tests (*global*)
    * major nuclear accidents (*regional*)
    * radiological accidents (*local*)

Modes of exposure

- External exposure
  - penetating radiations
    - gamma rays
    - cosmic radiation
- Internal exposure
  - inhalation
  - ingestion
  - skin contamination

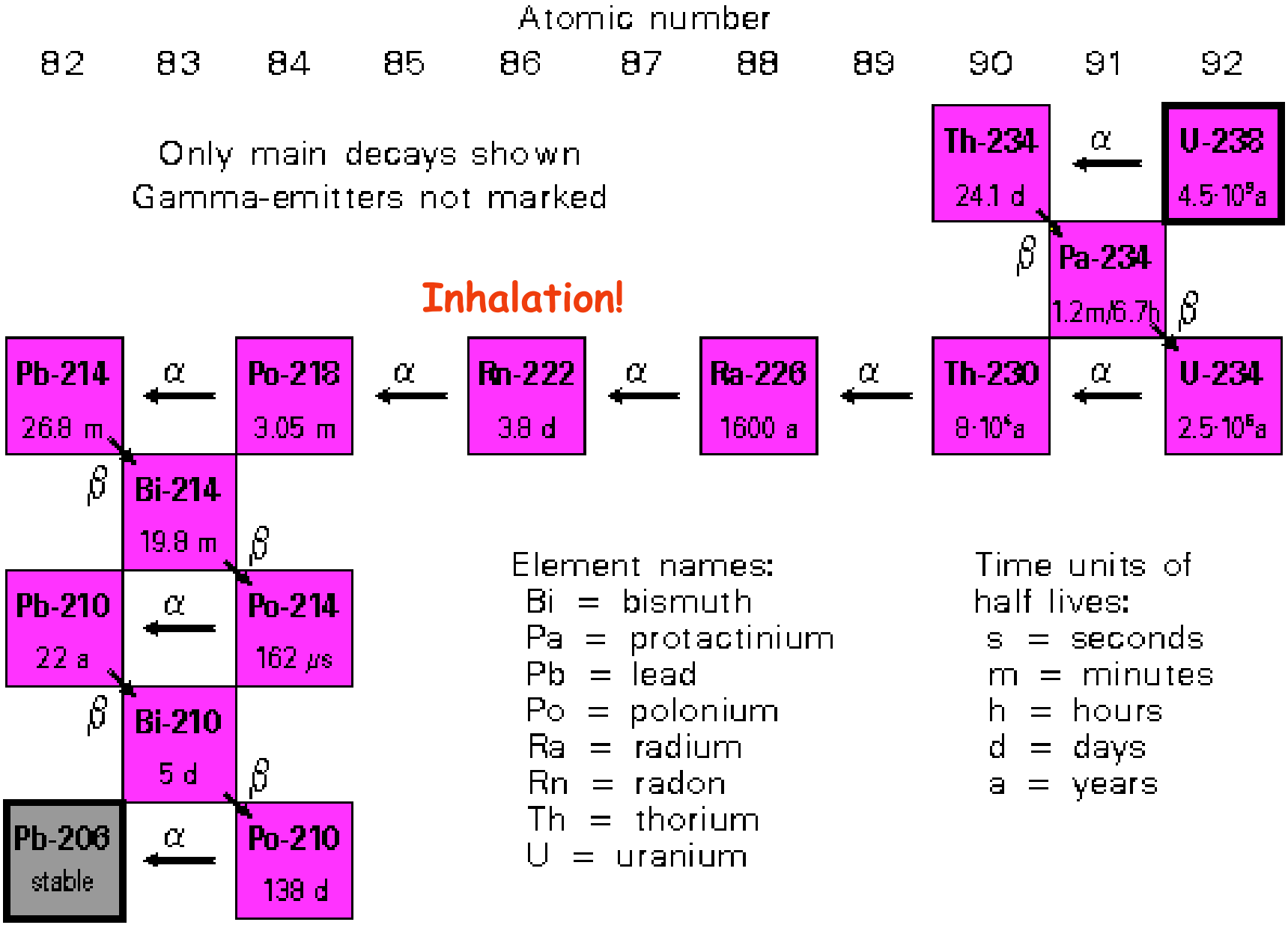
Natural radionuclides

- **Terrestrial long-lived radionuclides**
  - * nonseries: K-40
  - * series: U-238+, Th-232+, U-235+
- **Cosmogenic radionuclides**
  - * tritium (H-3), radiocarbon (C-14)

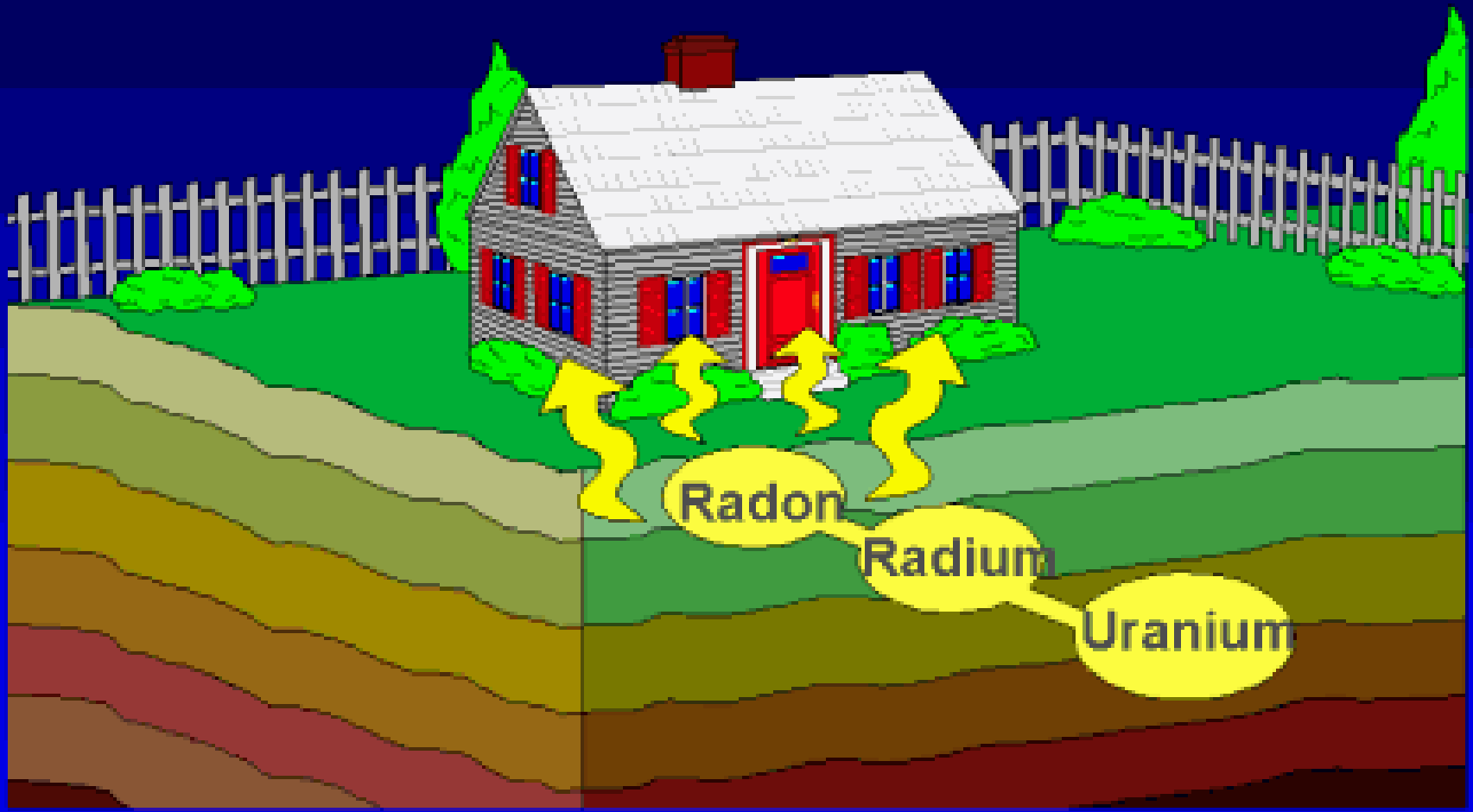
Primordial (terrestrial) radionuclides

Radionuclide	$T_{1/2}$ (years)	Major radiations
K-40	1.26 G	beta, gamma
Th-232+	14 G	alpha, beta, gamma
U-238+ (Rn-222+)	4.47 G (3.83 d)	alpha, beta, gamma
U-235+	0.704 G	alpha, beta, gamma

The uranium-238 decay chain



Uranium is the source for Radon

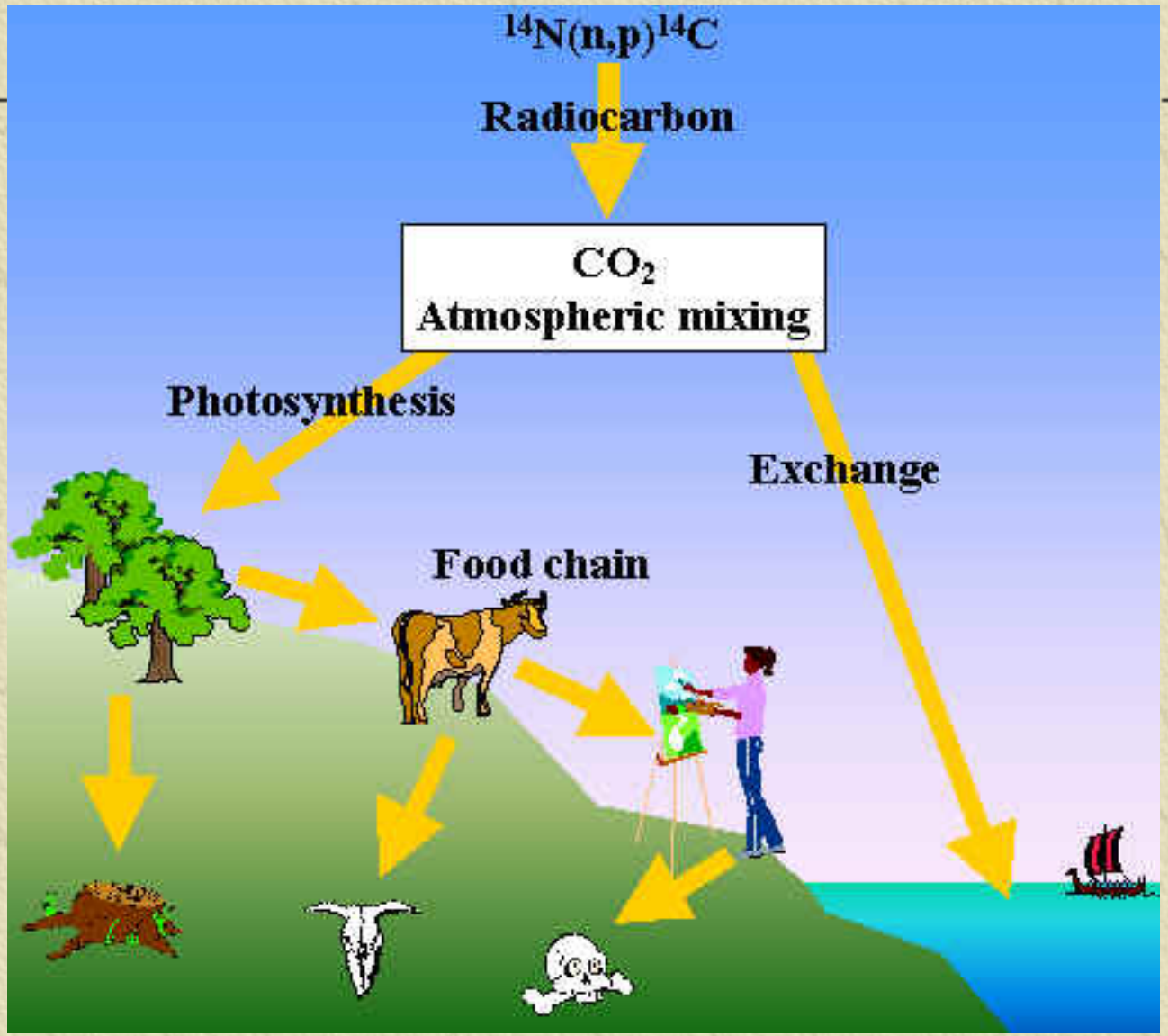


Cosmogenic radionuclides

Radionuclide	$T_{1/2}$ (years)	Decay mode
Tritium (H-3)	12.3	pure beta (max. 18.6 keV, av. 5.9 keV)
Radiocarbon (C-14)	5730	pure beta (max. 156 keV, av. 50 keV)

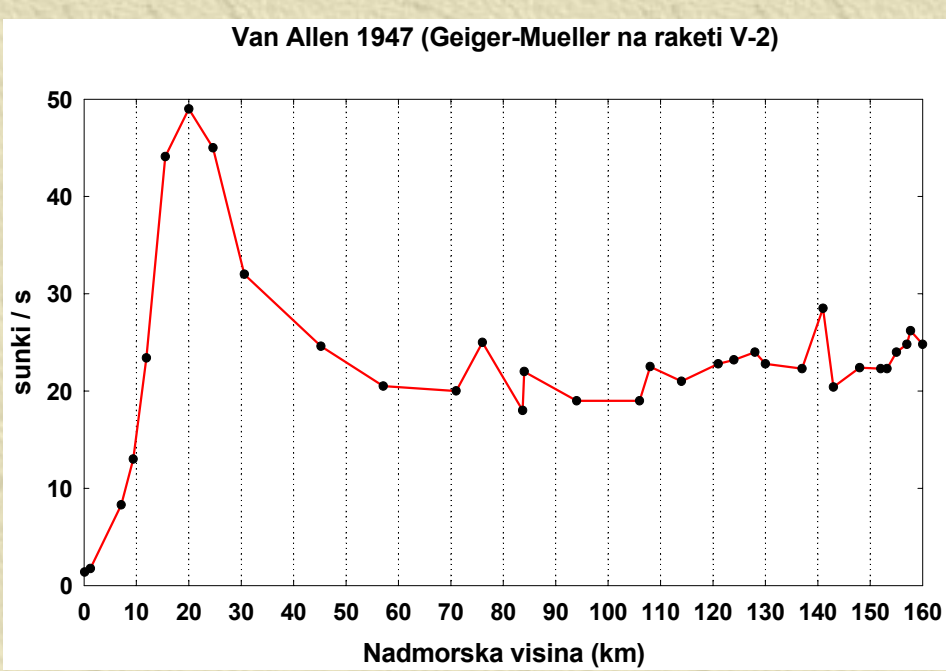
Internal exposure only!

C-14 cycle

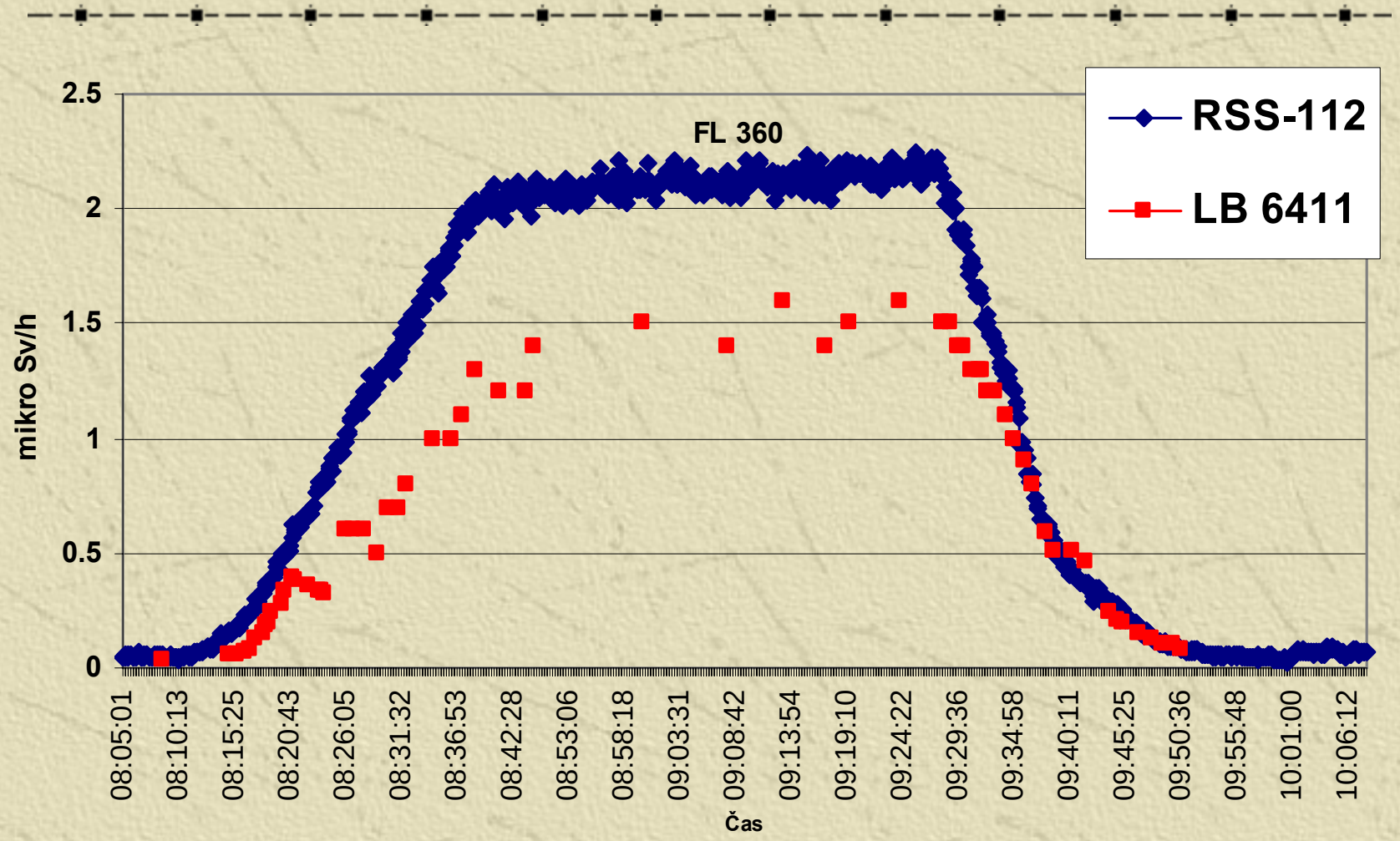

$^{14}N(n,p)^{14}C$
Radiocarbon
CO_2
Atmospheric mixing
Photosynthesis
Exchange
Food chain

Cosmic radiation
Victor Hess (1912)

Victor Hess before his 1912 balloon flight in Austria, during which he discovered cosmic rays



Flight Ljubljana - Copenhagen



Radiation exposure in aircraft

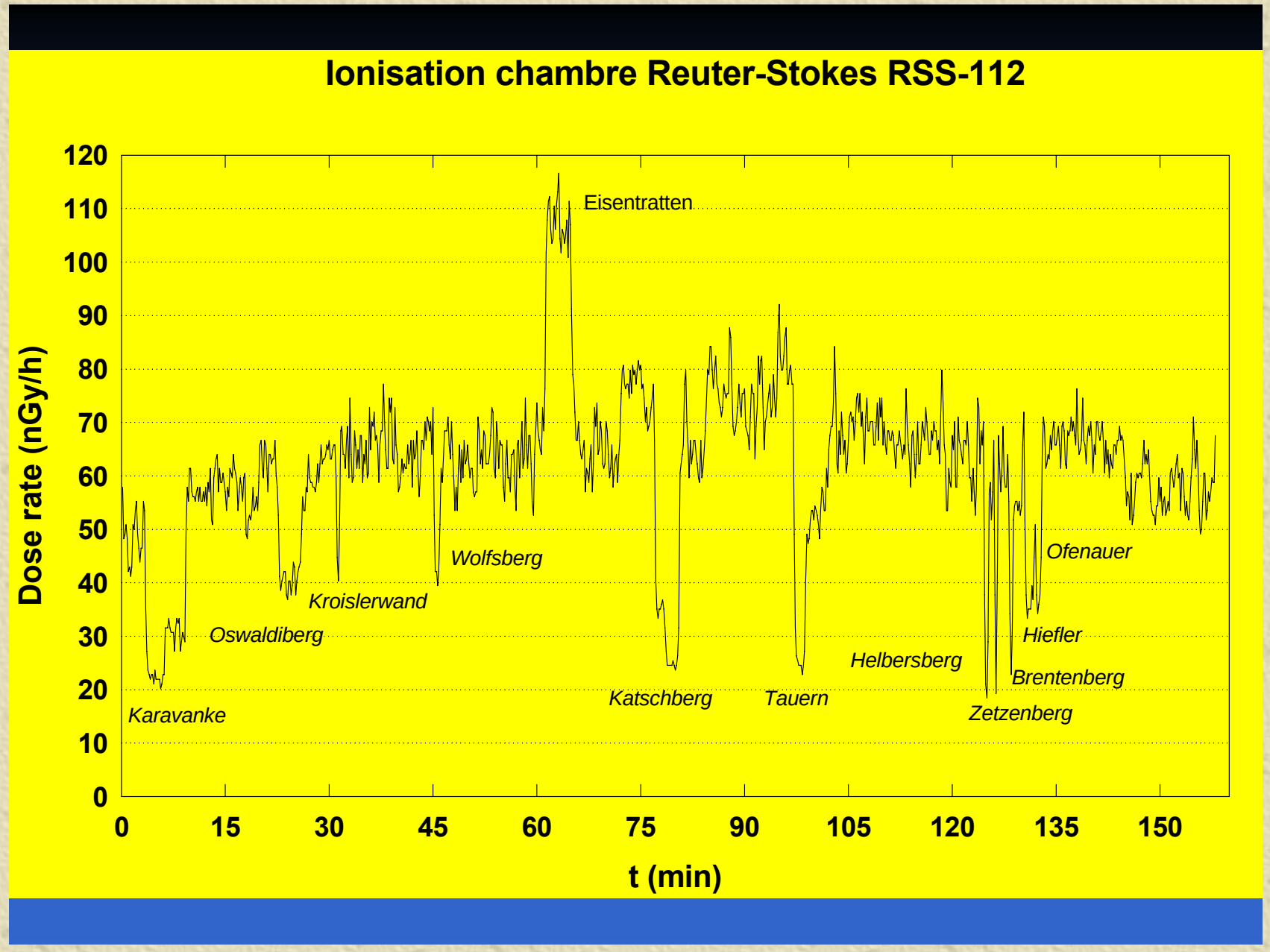
- height above sea level
- pole > equator

Europe – USA ~ 40 µSv

Exposure to natural radiation (UNSCEAR 2000)

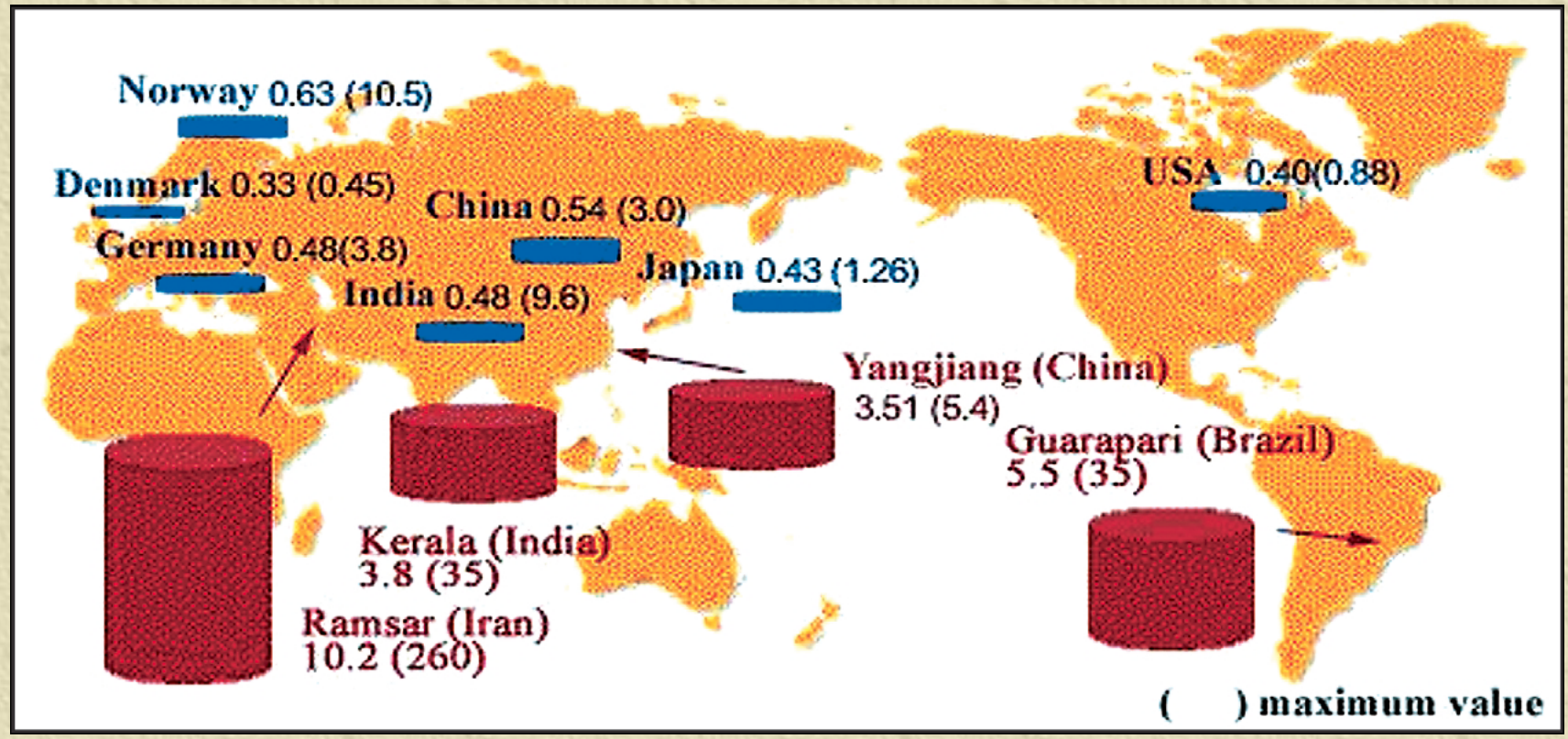
Annual effective dose (mSv)

Source	Average	Range
Cosmic radiation	0.39	0.3 – 1.0
External terrestrial radiation	0.48	0.3 – 0.6
Inhalation (Rn-222+)	1.26	0.2 – 10
Ingestion	0.29	0.2 – 0.8
Total	2.4	1 - 10


Ionisation chambre Reuter-Stokes RSS-112
Dose rate (nGy/h)
t (min)
0
10
20
30
40
50
60
70
80
90
100
110
120
0
15
30
45
60
75
90
105
120
135
150
Karavanke
Oswaldiberg
Kroislerwand
Wolfsberg
Eisentratten
Katschberg
Tauern
Helbersberg
Zetzenberg
Brentenberg
Hiefler
Ofenauer

High radiation areas

(external dose from natural nuclides: mSv/year)

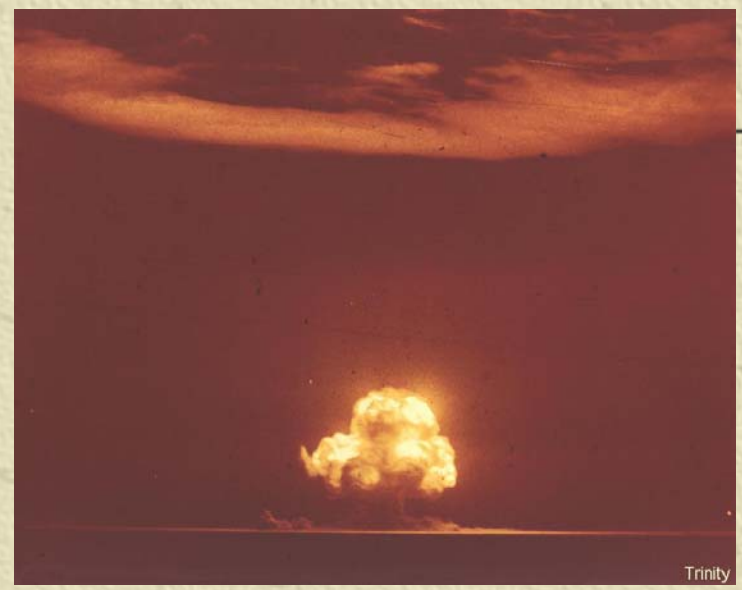


Average external dose: 0.87 mSv/year

Natural nuclides: 0.48 mSv/y

Cosmic radiation: 0.39 mSv/y

Nuclear weapons



TRINITY 16.7.1945

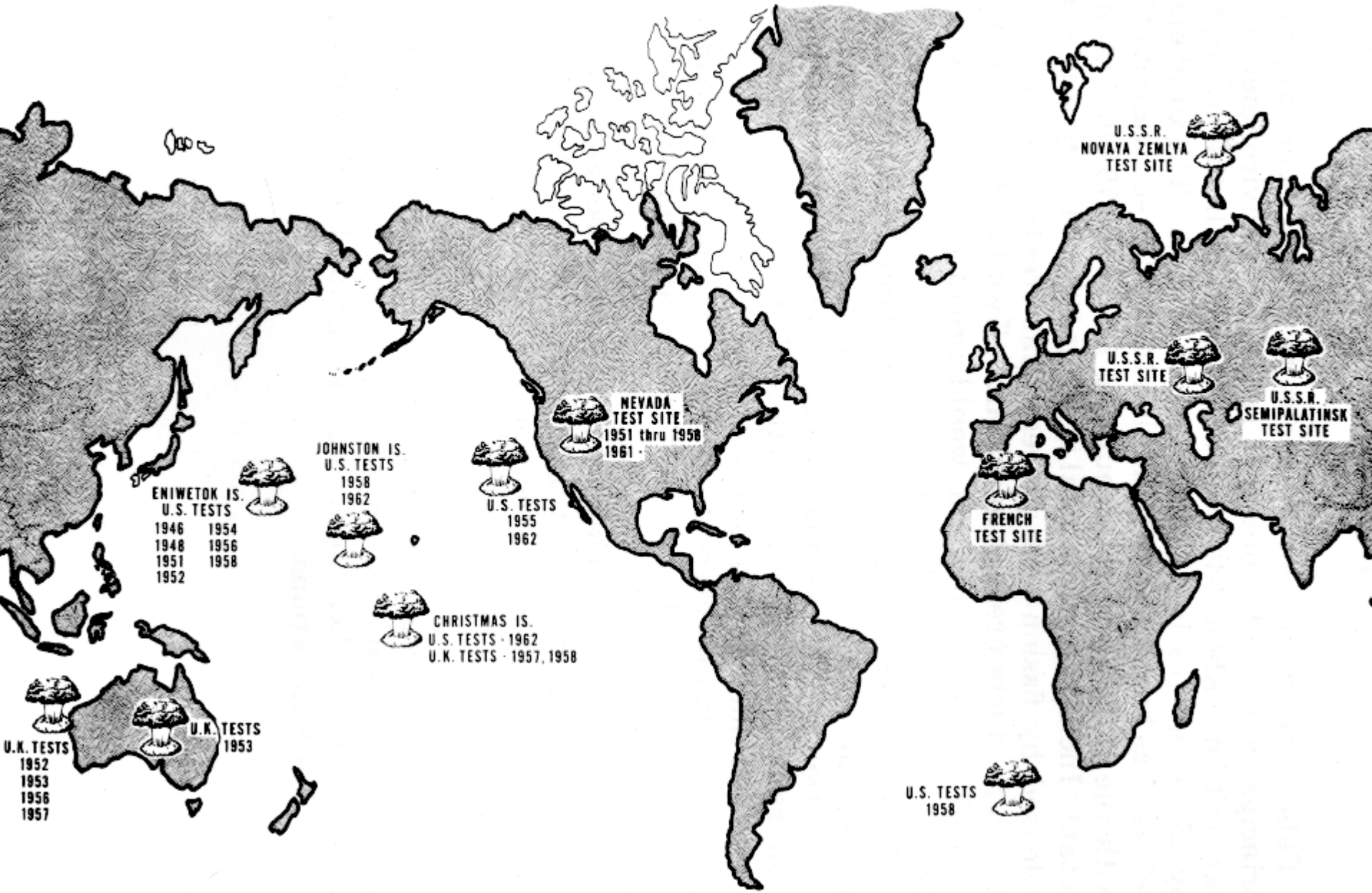
2053 weapons tests – 510 Mt

530 atmospheric tests

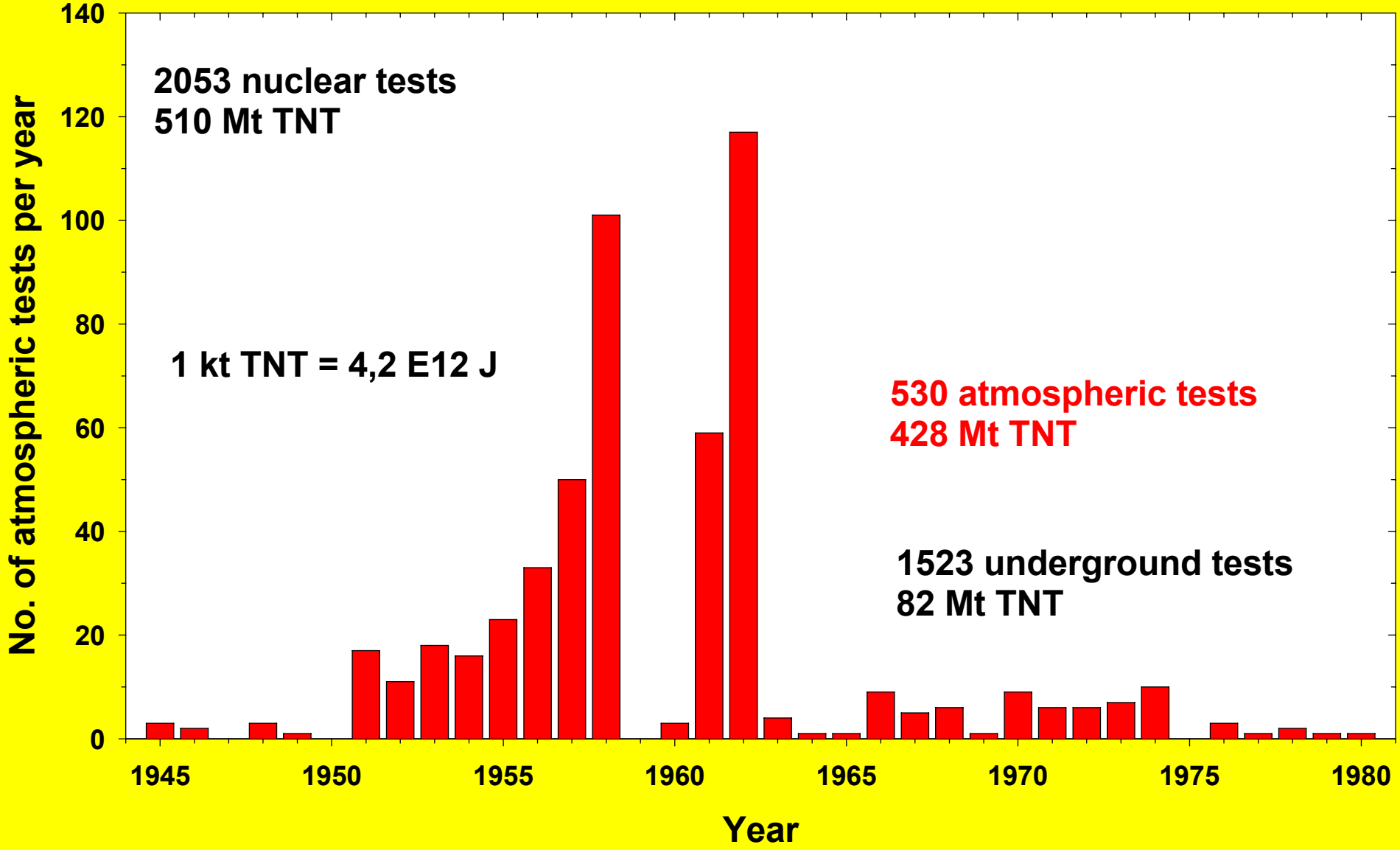
Hiroshima 15 kt (6.8.1945)

Nagasaki 20 kt (9.8.1945)

LOCATIONS of NUCLEAR WEAPONS TEST SITES



Nuclear test explosions

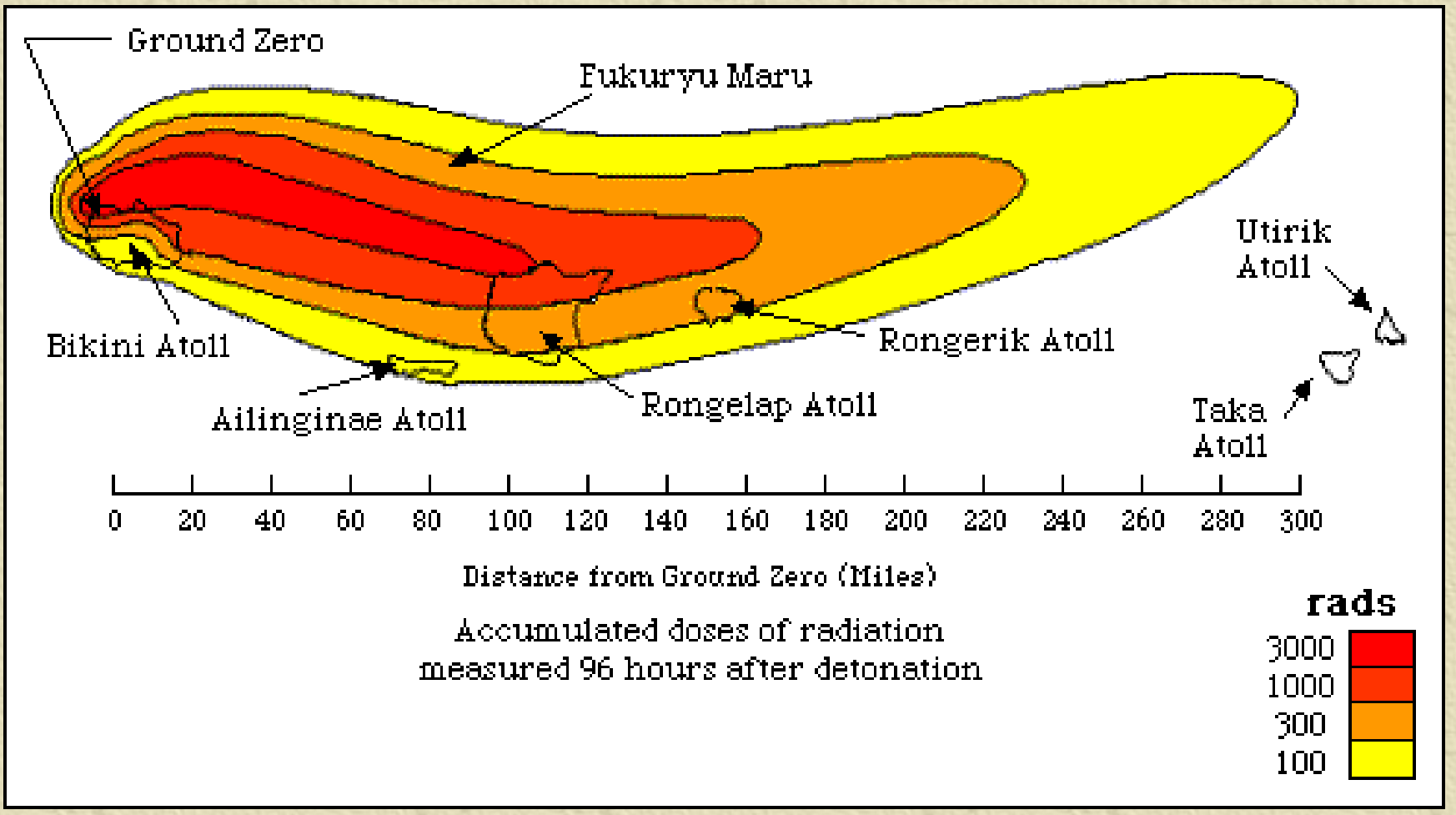


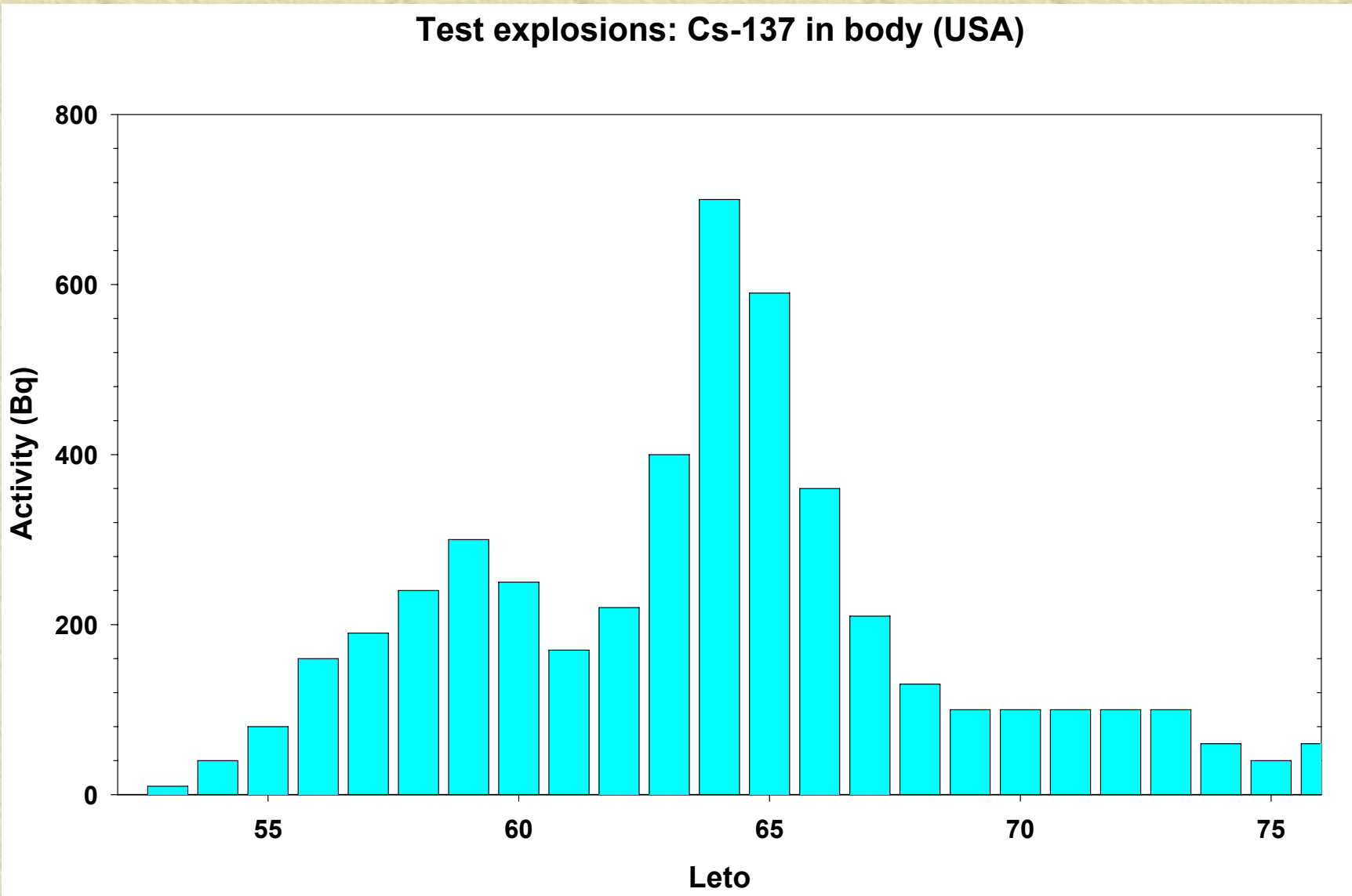
Radionuclides from nuclear weapons tests

Radionuclide	$T_{1/2}$	Radiations	Target organ
I-131	8.04 d	beta, gamma	thyroid
Sr-90	29 y	beta	bone
Cs-137	30 y	beta, gamma	whole body

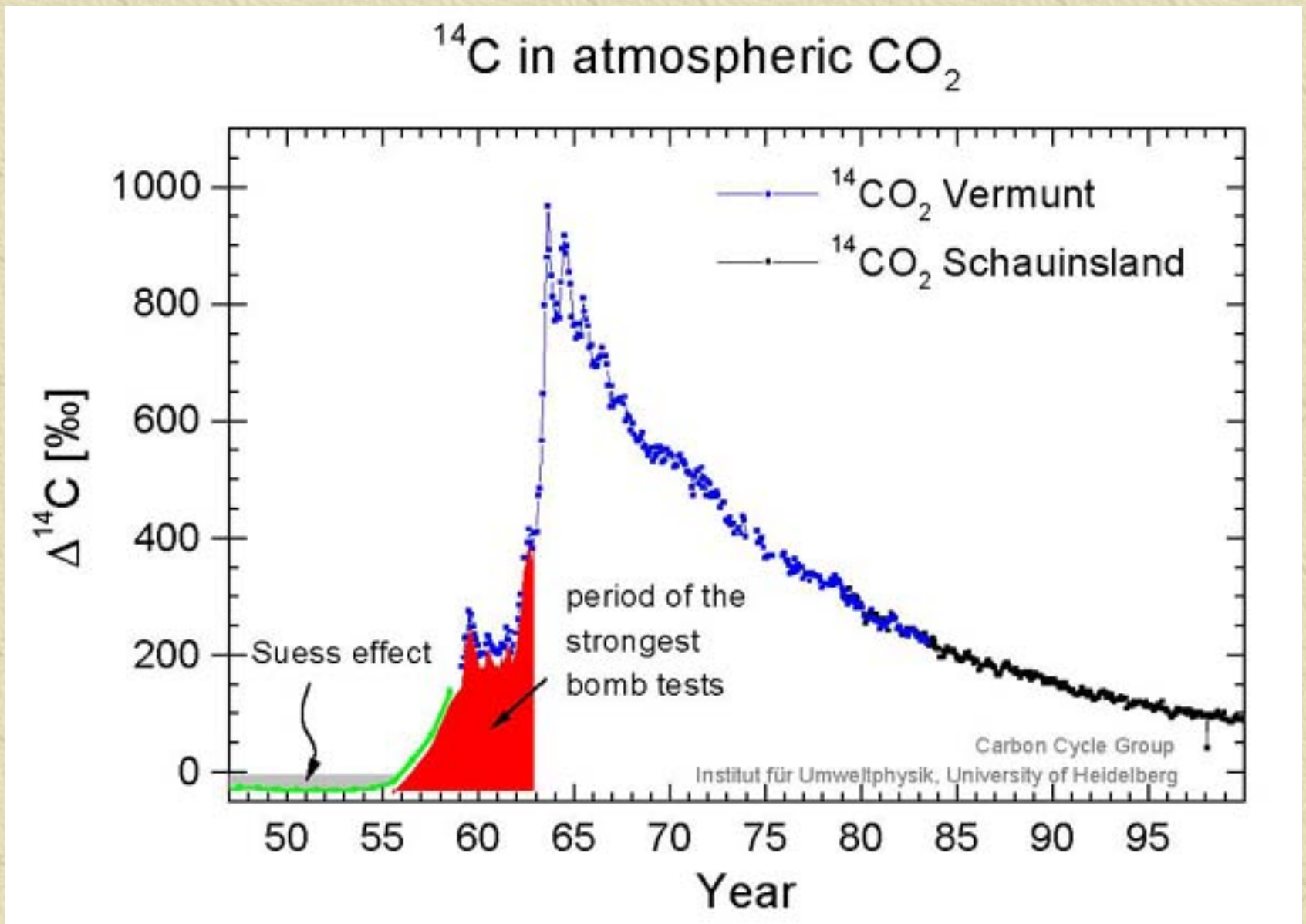
THERMONUCLEAR Test *BRAVO*
Bikini 1954, 15 Mt

Test BRAVO
Fall-out exposures in 96 h




Test explosions: Cs-137 in body (USA)
800
600
400
200
0
Activity (Bq)
55
60
65
70
75
Leto

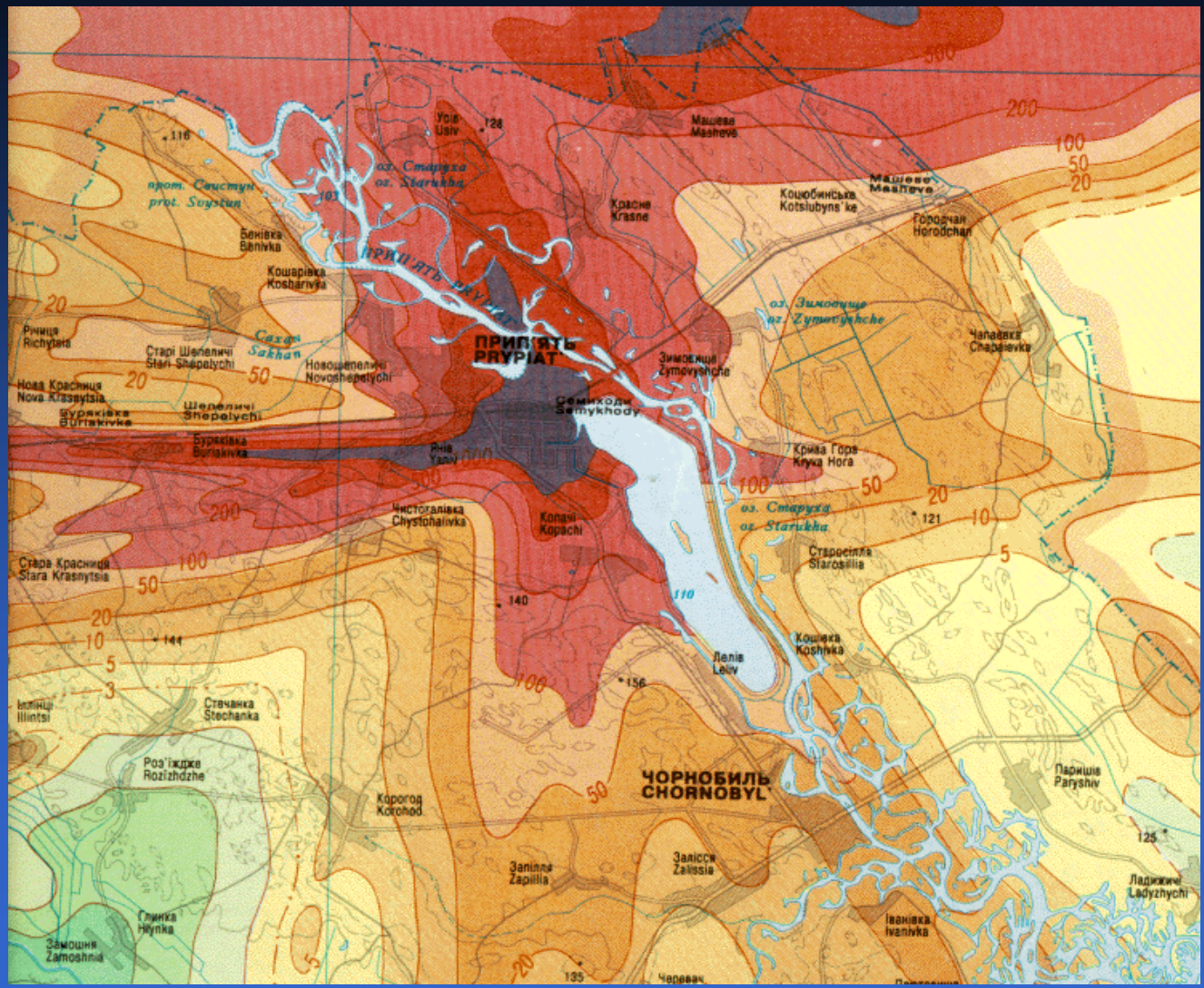
C-14 in air


^{14}C in atmospheric CO_2
$^{14}CO_2$ Vermunt
$^{14}CO_2$ Schauinsland
$\Delta^{14}C$ [‰]
1000
800
600
400
200
0
Suess effect
period of the
strongest
bomb tests
Carbon Cycle Group
Institut für Umweltphysik, University of Heidelberg
50
55
60
65
70
75
80
85
90
95
Year

Chernobyl, 26.4.1986

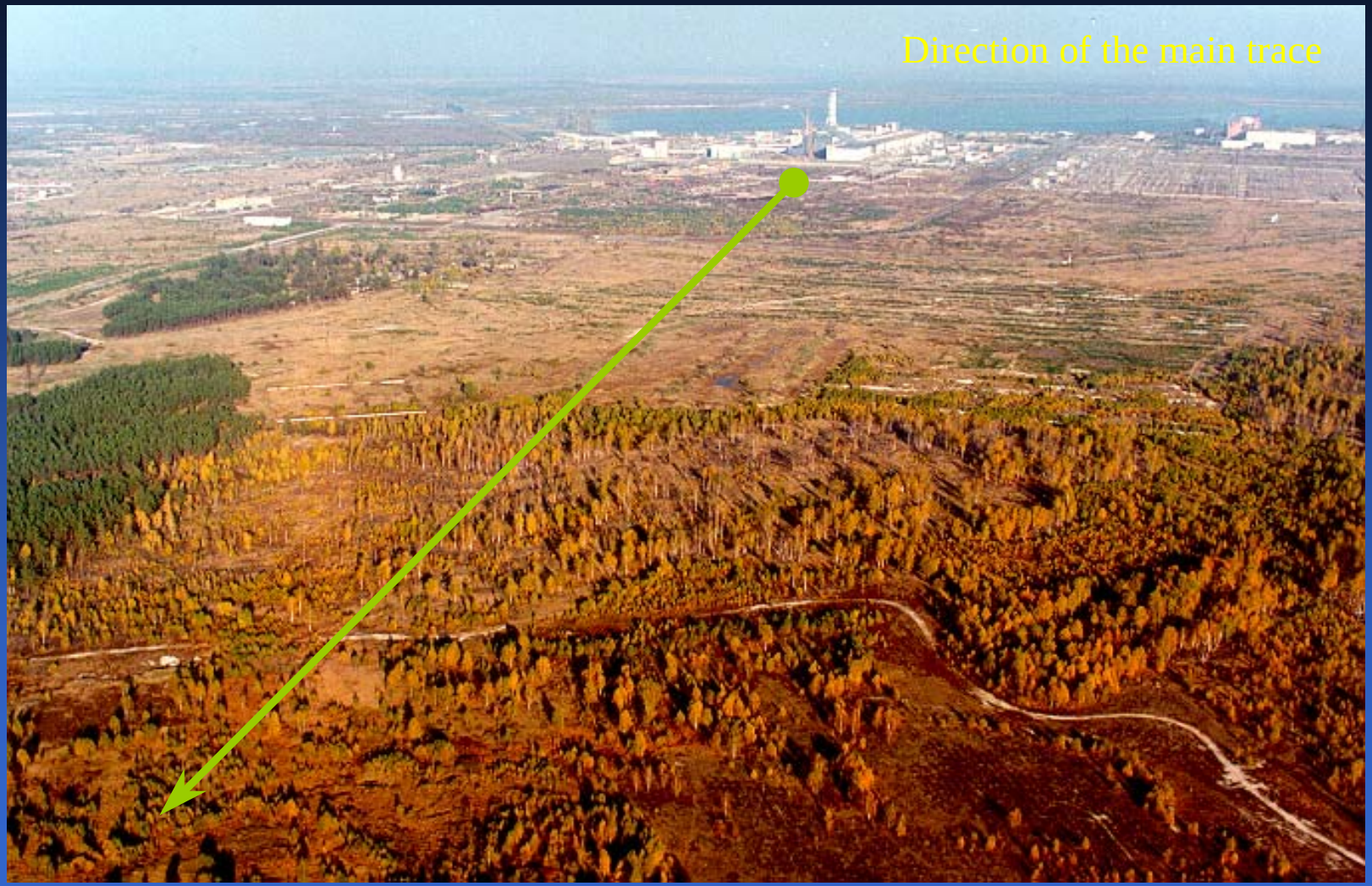
Former Chernobyl reactors

Contamination map



"Red forest"

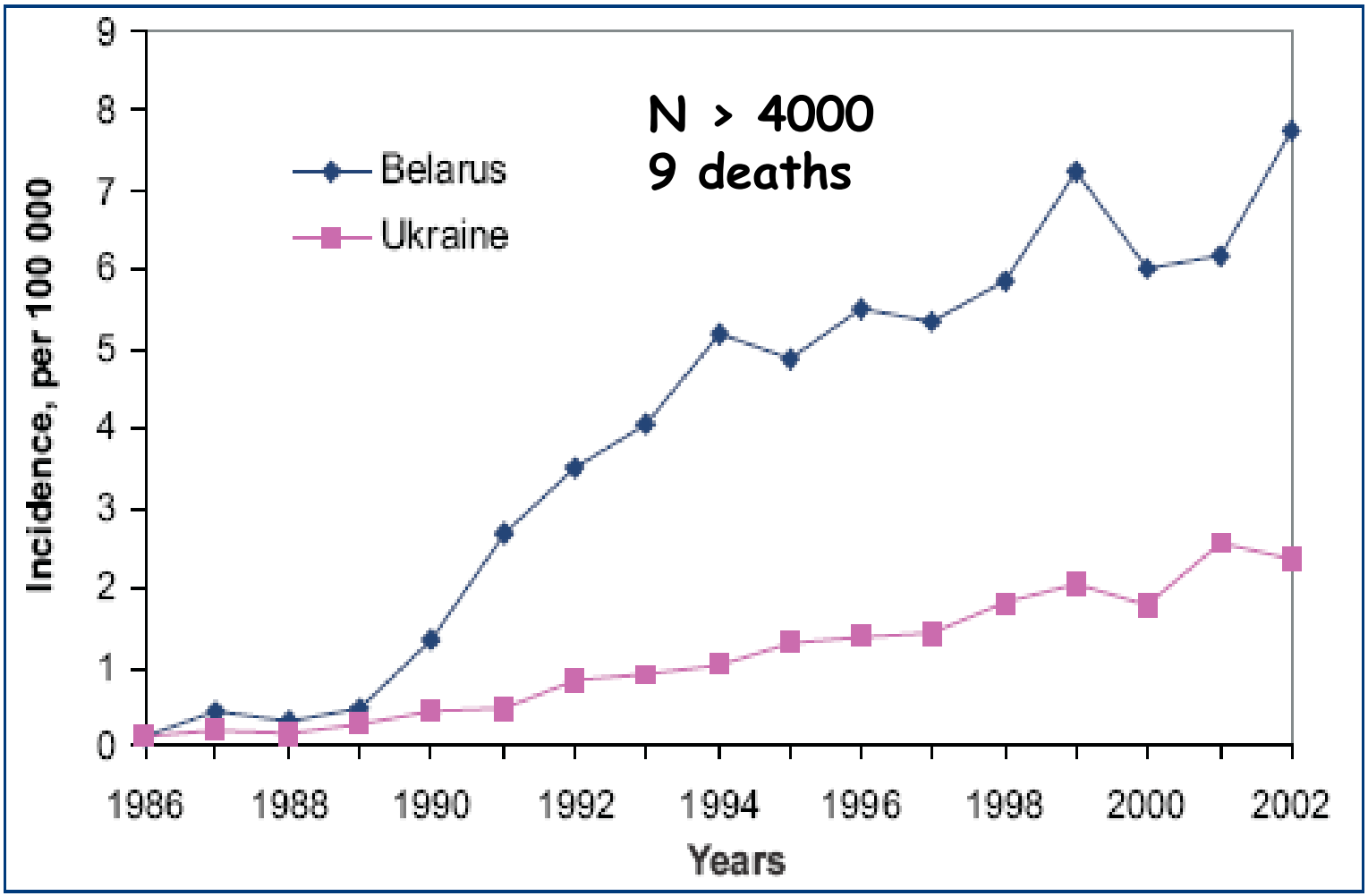
byAndriy Arkhypov

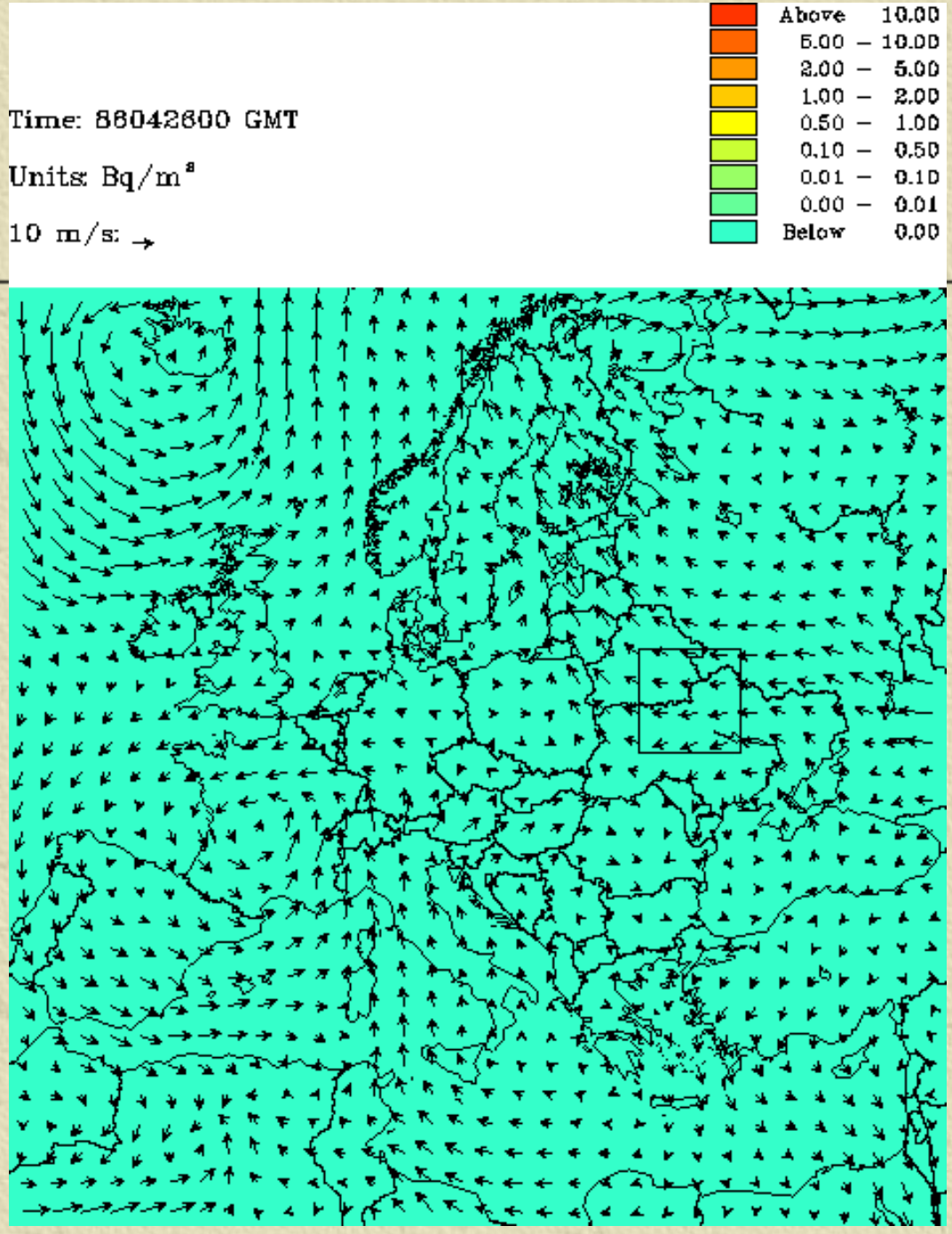


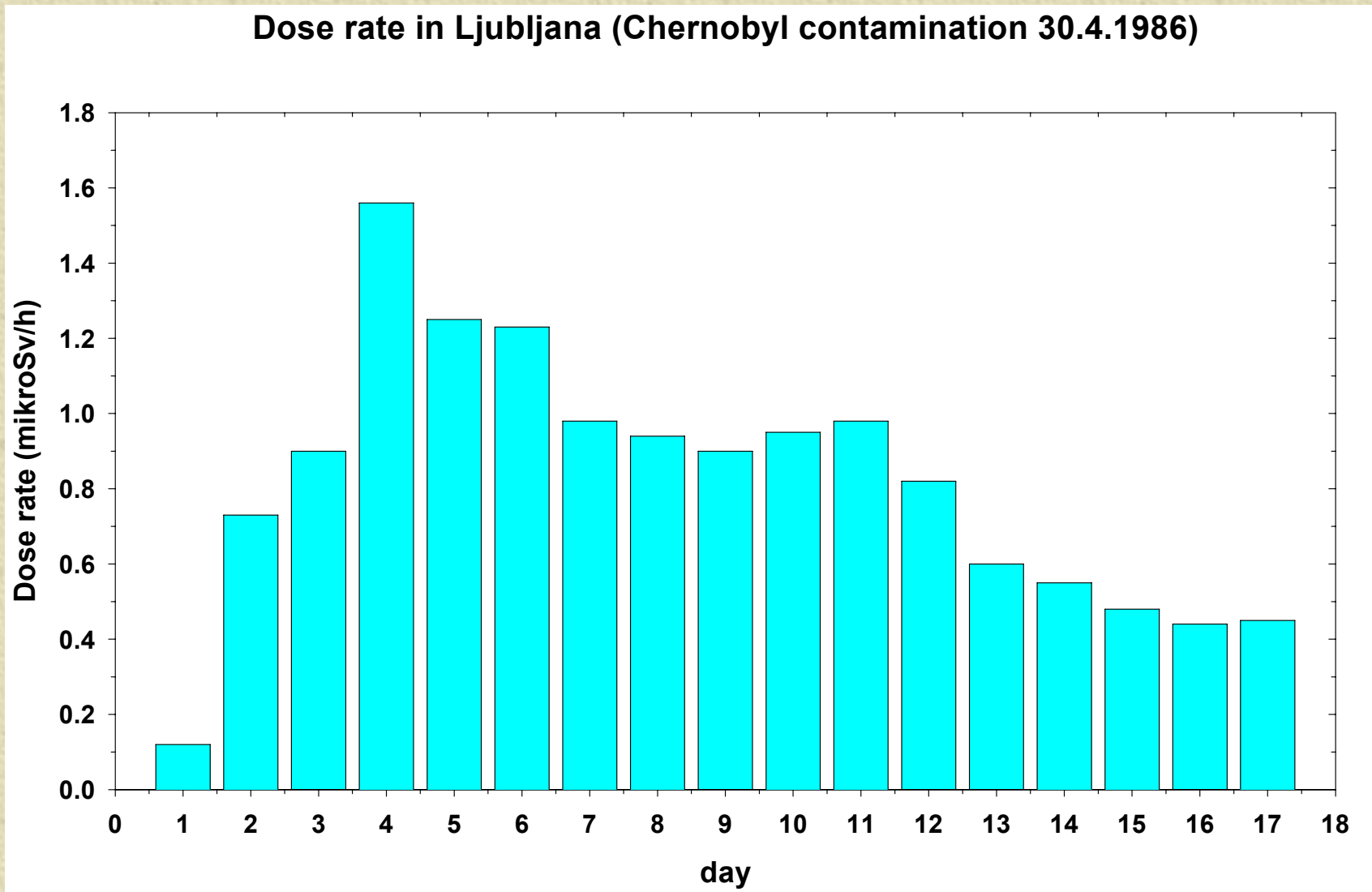
Chernobyl exclusion zone

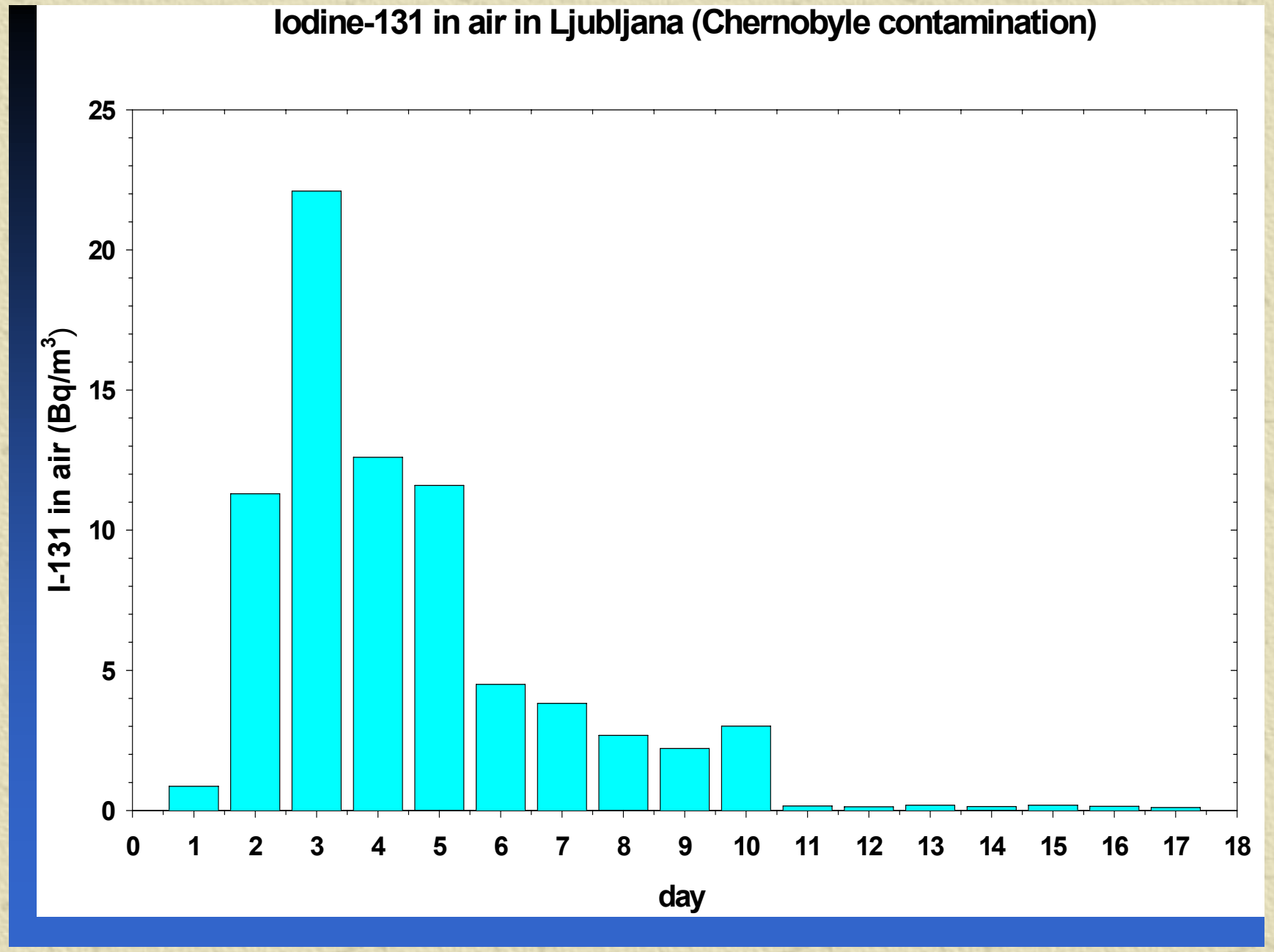
(National Geographic, April 2006)

Incidence of thyroid cancer in children




Time: 86042600 GMT
Units: Bq/m³
10 m/s:
Above 10.00
5.00 – 10.00
2.00 – 5.00
1.00 – 2.00
0.50 – 1.00
0.10 – 0.50
0.01 – 0.10
0.00 – 0.01
Below 0.00


Dose rate in Ljubljana (Chernobyl contamination 30.4.1986)
Dose rate (mikroSv/h)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
day


Iodine-131 in air in Ljubljana (Chernobyle contamination)
I-131 in air (Bq/m3)
0
5
10
15
20
25
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
day

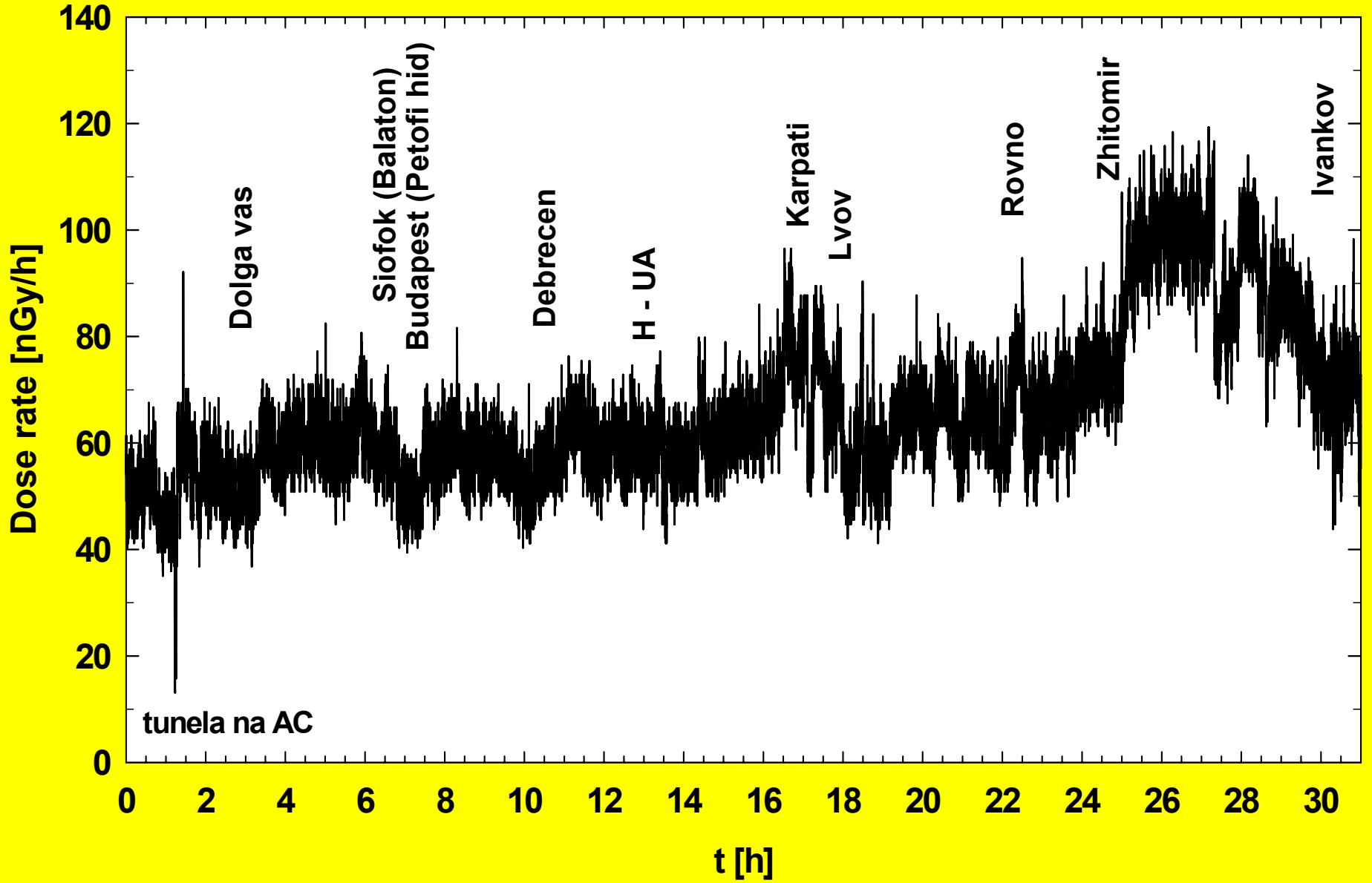
Ljubljana – ground deposition

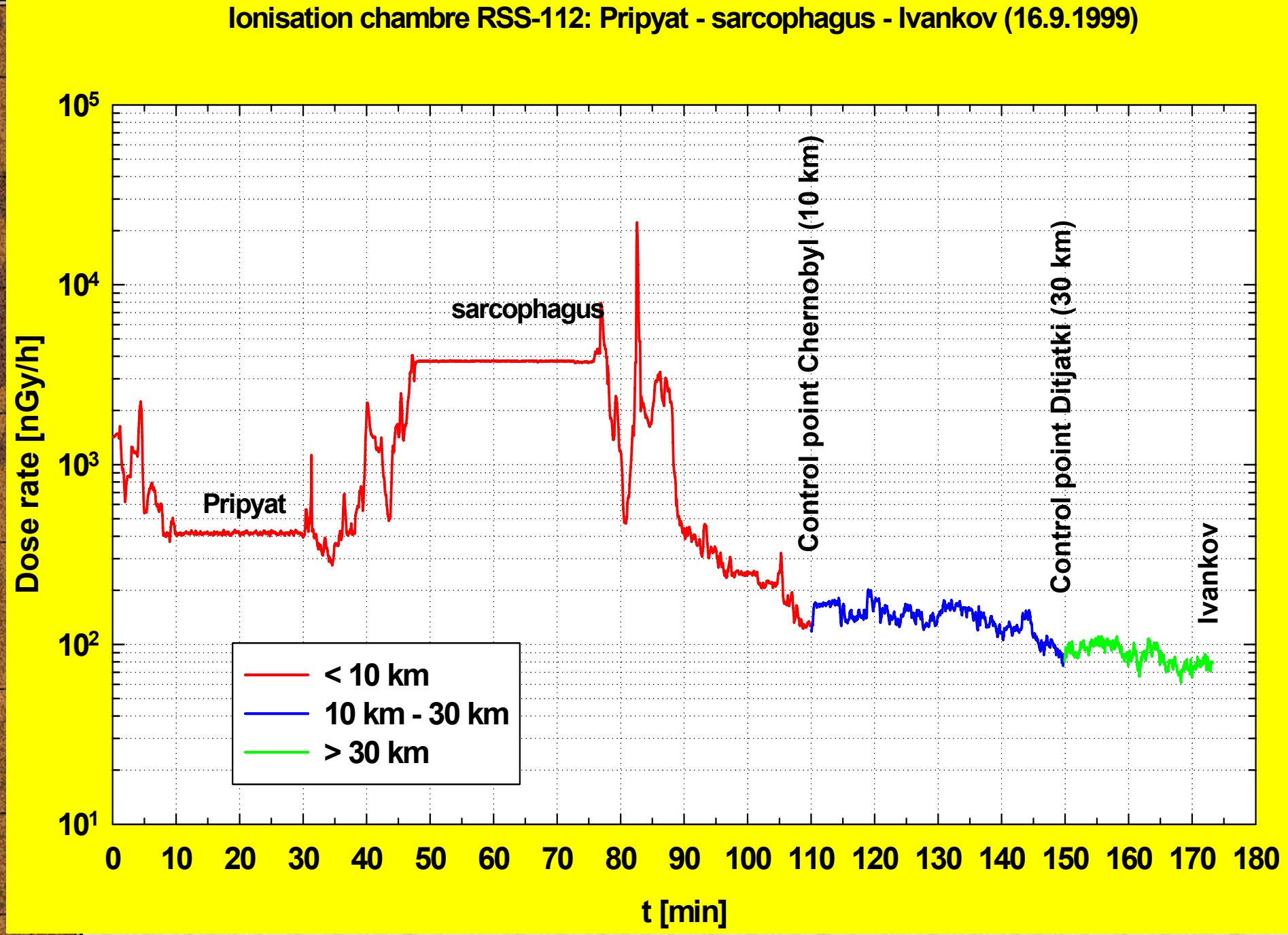
Bq/m^2

Radionuclide	Weapons tests	Chernobyl
I-131	?	100,000
Cs-137	5000	20,000
Sr-90	3500	400

Ionisation chambre RSS-112: Ljubljana - Ivankov

$\Delta t = 5$ s




Ionisation chambre RSS-112: Pripyat - sarcophagus - Ivankov (16.9.1999)
Dose rate [nGy/h]
10^5
10^4
10^3
10^2
10^1
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
t [min]
Pripyat
sarcophagus
Control point Chernobyl (10 km)
Control point Ditjatki (30 km)
Ivankov
< 10 km
10 km - 30 km
> 30 km

Goiânia (Brazil) - 1986

Goiânia – sealed source

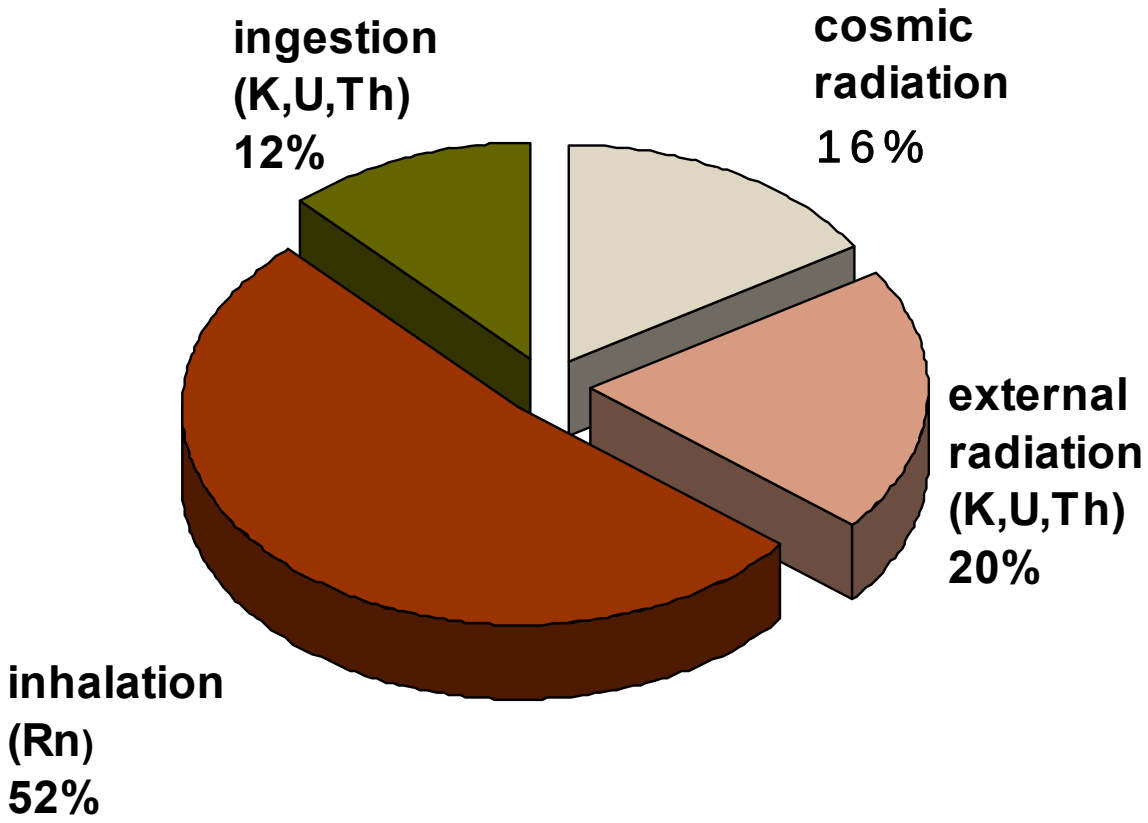
- Teletherapy sealed source
- Cs-137 in the form CsCl
- A = 1400 Ci = 52 TBq
- Dose rate at 1 m: 4 Gy/h!

Decontamination, waste collection

Goiania -consequences

- 4 victims
- pschological traums in population
- extensive decontamination (300 man . years)
- 3500 m^3 of radioactive waste
- 20 M US$ of direct expenses

Dose cake (UNSCEAR 2000)



Σ = 2,4 mSv/year

Thank You

for Your patience!